Wet Weather Management of the Sam Houston Multi-Use Trail System: An Evidence-based Approach

prepared for

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by

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Executive Summary

This document provides a wet weather management plan for the Sam Houston Multi-Use Trail (SHMUT) system that is evidence-based, and has the support of user groups and on-the-ground trail managers. This evidence-based approach uses measurements of soil strength and soil moisture to predict the risk of trail damage. The objective is to manage the trail system during wet weather to provide sustainable recreational opportunities while minimizing impacts to resources. This document stresses the importance of proper planning and trail layout, use of breaks in grade, sediment traps, and re-routing, rather than relying strictly on closures to prevent damage to trails. An important component of the success of this method has been the inclusion of user groups in the development of the method; on-site training was given to a group of dedicated volunteers and Forest Service employees.

Most trails in the SHMUT system are single track. Use is about 80% by motorcycles and 20% by ATVs. Most single-track trails were user-designed. A few trails are on old roadbeds. Downfall and potholes have caused trail braiding in many places. Some trails are rutted where they cross poorly drained soils. Water retention in potholes and wet areas could influence decisions to close the area after rainfall, but most potholes have solid bottoms and are not of concern except to the extent that they lead to braiding. Lack of drainage and poor trail location are more serious problems. Some trail segments are not sustainable because of ineffective drainage, or poor location or design. These situations should be addressed, rather than relying on closure to prevent damage. Solutions may include maintaining or installing drainage structures, rerouting, trail hardening, and other trail management techniques.

Winter season precipitation in the area is characterized by frequent low-intensity, long-duration frontal storms, while summer storms are less frequent but more intense, shorter in duration, and often localized.

Typically, wet season closures are based on rainfall, on drying periods between rainfall events, on storm forecasts, or some combination. Because it is difficult to directly correlate rainfall with actual damage to trails, this report proposes an evidence-based methodology that bases opening and closing trails on the risk of damage to drainage structures and trail treads by correlating soil moisture and soil strength with observations of trail damage under traffic typical for the area.

Allowing some OHV traffic on moist soils is desirable because the traffic helps compact the tread, making it resistant to wear. Opening trails when soils are too wet results in trail damage, but waiting longer than necessary to open trails forgoes the benefit of compaction that traffic provides. Criteria for trail closures in this report are evidence-based, i.e., based on measurements of soil strength and soil moisture, which predict the risk of trail damage.

In recent years the SHMUT system has frequently been closed after rainfall to prevent trail damage. Many users felt the closure policy was arbitrary, lacking in foundation, and overly restrictive. The Sam Houston National Forest has recently upgraded numerous watercourse crossings with bridges and arch culverts to minimize sedimentation, but more work is needed on other factors that affect wet weather use. Particularly important are reinstalling drainage structures, assessing and redesigning trails, and implementing the wet weather management policy provided in this report.

A wet weather closure is only one of several tools for managing wet weather use. Equally important are trail location, trail layout and design, watercourse crossing design, trail drainage and maintenance, and effective management.

This report proposes six steps to implement a wet weather management plan:

- Clear out downfall and drain potholes.
- Assess trail condition and take appropriate action to correct problems.

- Continue to upgrade watercourse crossings.
- Implement the evidence-based wet weather management policy described in this report.
- Monitor the implementation and effectiveness of the wet weather management policy; monitor trail condition and long-term trends.
- Schedule long-term rerouting and restoration, and protect existing infrastructure.

Introduction

This report provides a basis for managing wet weather use on native surfaced trails of the Sam Houston Multi-Use Trail (SHMUT) system. The objective of wet weather management is to sustain recreational opportunities while minimizing impacts to resources. The sustainability of native surfaced trails is strongly influenced by soil type and by soil strength and moisture at the time of use.

The area was first visited on April 10-11, 2008. About 95% of the trails were traveled by ATV and observations were made on trail condition, soil types, watercourse crossings, trail location and design, and maintenance. On April 12 several volunteers and riders were interviewed.

During May 2008 phone calls were made to local National Forest personnel to obtain information on weather patterns, historical use, maintenance, and other information about the trail system. Soil maps were obtained from the NRCS web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/).

Additional field trips were made to measure soil moisture and strength under wetting and drying conditions. Measurements were made under a wetting front during September 2009 and under a drying front in January 2010. The data collected were analyzed to develop threshold values to use in determining when to open and close trails. Additional measurements were made in April 2012 to calibrate the threshold values using a different type of moisture meter.

Site Properties

Typical Single Track Trail

TRAIL SYSTEM

Most trails are single track and fairly narrow. Motorized use is about 80% by motorcycles and 20% by ATVs. Treads tend to be wider near trailheads, where ATV use is higher. Most of the single-track trails were user-designed. A few trails are on old roadbeds. Some trail segments are not sustainable because of poor location and design.

LANDSCAPE AND WATERCOURSES

The overall landscape is level to gently sloping. Many watercourses are deeply entrenched. Entrenchment tends to be deeper on the west side of Lake Conroe. Bridges have been installed at many crossings. Most approaches to the less entrenched watercourse crossings, such as small ephemeral drainages, have been hardened with paver blocks.

PRECIPITATION

Precipitation varies by season. In the winter (November through March), several frontal storms can occur weekly. These storms tend to be low in intensity but long in duration (12 to 24 hours or more). In the summer (June through August) storms are less frequent, but tend to be high intensity, short duration (hour or less) events. It is not uncommon to get one very intense storm (4 to 10 inches in less than 6 hours) during the summer season. Summer storms are often localized and confined to a small portion of the area. The typical weather pattern creates several wetting and drying cycles during the year that make it necessary to open and close the trails to protect trails from damage when soils are too wet.

Wider Trail Near Staging Area

EVAPOTRANSPIRATION

During the summer, temperatures and evapotranspiration are high. Because most of the trails in the area are single track, subgrades contain live roots. Consequently, trails dry out very rapidly after summer storms. This means trails can often be opened shortly after summer rainfall. However, during the winter, when vegetation is dormant and ambient temperatures are lower, trails dry out more slowly after storms. This means closures during the winter tend to be longer.

SOILS

The following broad grouping of soils is based on field observations made during the initial reconnaissance. A more detailed analysis of soil distribution and response to OHV use was done in January 2009. The detailed groupings of soils were based on the Montgomery and Walker County Soil Surveys (McClintock et al. 1967; McClintock et al. 1979) made by the NRCS and were provided to the SHNF for use in trail management. These more detailed groupings of soils are on maps on file at the SHNF office.

Deep sandy soils

Deep sandy soils were observed at the north end of the area west of Lake Conroe, and in the far western and far eastern sections of the area on the east side of Lake Conroe.

These soils have a high rate of infiltration. Slope runoff is low. Cohesion is low, making these soils very susceptible to gully erosion. Although sandy, these soils do contain enough fines to compact well under optimum moisture conditions. Trails on these soils have fewer wet spots than on other soils in the area, and the puddles that occur in them drain rapidly. Deep sandy soils are more easily displaced and tend to develop “whoops” and high outside banks on turns.

“Whoops” in Deep Sandy Soils

Sandy over clayey soils

These soils occur primarily in the middle section of the area on the west side of Lake Conroe and down the middle of the trail system on the east side of the lake. Surface infiltration is rapid, but permeability in the clayey subsoil is slow. Consequently, water moves laterally downslope at the sand/clay interface. Cross slope trails on these soils typically intercept this subsurface water.

Trails on the sandy over clayey soils tend to have more wet spots than trails on the deep sandy soils. The sandy over clayey soils are also less prone to developing “whoops.” The underlying clay in these soils compacts well, so treads and rolling dip structures hold up well to traffic.

Clay soils

Clayey soils were observed near the north end of the area on the east side of Lake Conroe, and southwest of Road 1375 on the west side of Lake Conroe in the Kelley’s Pond area. The clayey soils tend to be chronically wet and are prone to deep rutting. Potholes develop more readily in the clayey soils than on the other soil types.

Wet Weather Trail Management

SOIL PROCESSES

In order to understand the logic of using an evidence-based trail closure to prevent trail damage during wet weather, it is necessary to understand how wet weather traffic damages trails. The following discussion provides this background.

Soil Strength and Moisture

Soil Compaction, Puddling, and Rutting

Soil consists of about half solid particles and half open spaces, or pores. Compaction can be thought of as squeezing the air out of the soil. Compaction occurs when soil pores are partially filled with water and partially filled with air. As soils compact, pore volume decreases, density increases, and soil strength increases. Compaction cannot occur when all the soil pores are filled with water, that is, when the soil is saturated. When saturated, soil has low strength and low bearing capacity. Puddling and rutting occur when soil is saturated (Alexander and Poff 1985).

Soil compaction on native surfaced trails is desirable. Well-compacted treads hold up under traffic, and are less susceptible to displacement and soil loss by dusting when soils are dry. Drainage structures (rolling dips) must be well compacted to hold up under traffic. It is necessary to construct and maintain rolling dips with mechanized equipment when soils are moist to achieve maximum density and strength (Poff and Ryan 2001).

Beneficial Effects of Motorized Traffic

Vehicle traffic can help compact trail treads. This compaction occurs when soils are moist, but not saturated. The optimum moisture content for compacting treads is just a little below saturation, when soil strength is low, but when some pores are air-filled and can be compacted (Poff and Ryan 2001).

Infiltration and Permeability

Soil infiltration and permeability affect how trails respond to rainfall events. Infiltration is the rate at which the soil absorbs water at the surface. Permeability is the rate at which water moves through the soil. The amount of water the soil can absorb in a given storm is also

affected by existing, or antecedent, soil moisture. Antecedent moisture is affected by the amount of rain in the previous storm, and by the drying conditions and length of time since the last storm.

Concentration of Runoff

Trails are linear features that concentrate water. Tread erosion is the major cause of deterioration on native-surfaced trails. The primary cause of tread erosion is concentrated runoff flowing down the trail. The power to erode increases as runoff volume accumulates (Parker 2004).

During and just after a rainfall event, there are three sources of water concentration on trails:

- Rain falling directly on treads, which accumulates and flows down the tread (except where the trail is completely flat);
- Subsurface lateral flow. On slopes with slowly permeable subsoil, absorbed rainfall migrates downslope as subsurface flow, which can be intercepted by trails.
- Rainfall concentrated by impervious surfaces—such as nearby roads and trails—that is drained directly onto a trail or onto a slope above a trail.

Runoff from impervious surfaces such as adjacent roads is the most serious of these three sources of concentrated runoff because the volume of water delivered to the trail is large. Interception of runoff from ephemeral drainages can also concentrate large volumes of water. Where soils are shallow to slowly permeable subsoils, trails can also intercept and concentrate subsurface flow. Finally, rain falling on the trail itself can accumulate between drainage structures if the structures are spaced too widely.

It is important to note that concentrated runoff causes erosion on trails with or without vehicle traffic, although traffic can loosen the soil and accelerate erosion to some extent.

ON-SITE VS. OFF-SITE IMPACTS

Wet weather damage to trails and associated resources occurs both on-site and off-site. On-site impacts occur to the trail itself. Rutting, damage to rolling dips, and loss of tread by displacement and erosion are examples of on-site impacts. On-site impacts can occur anywhere on the trail system.

Off-site impacts occur when soil eroded from the tread is delivered as sediment to a watercourse. Off-site impacts occur where trails are hydrologically connected to watercourses (Furniss, Flanagan, and McFadin 2000). Hydrologic connectivity is greatest at or near watercourse crossings. Only a small portion of the SHMUT system appears to be hydrologically connected. Off-site impacts can also occur where water drained from a trail causes erosion on the slope below it.

RESOURCE DAMAGE AND WET WEATHER TRAFFIC

Resource damage related to wet weather traffic can be grouped into three broad categories: rutting, tread erosion, and sedimentation. These categories differ in processes, causes, and types of treatment.

Rutting

Rutting is the result of traffic on soils when soil strength is low, that is, when soils are very wet or saturated.

Damage to Drainage Structures

The most serious impact of wet weather vehicle traffic is its potential to damage the rolling dip drainage structures (Poff 2006). Failed drainage structures lead to tread loss by erosion,

especially during major storm events. Wet weather closures are effective to the extent that they protect drainage structures.

The potential for damage to a rolling dip drainage structure depends on the soil strength of the dip structure. The soil strength is a function of how well the structure was compacted when it was constructed or maintained, and of its current moisture status, i.e., how much moisture the dip has absorbed and retained since the last rainfall, the design of the structure, and how it has been maintained.

Most rainfall will run off and not be absorbed into a well-constructed drainage structure. This means that short duration intense storms, typical of the summer season, are less likely to wet up rolling dips and make them susceptible to damage. However, during the winter season, when storms are more frequent and lower in intensity, there is a greater potential for drainage structures to absorb moisture and lose strength.

Rutting and Pumping in Treads

Ruts can develop when treads are wet and have low strength. Ruts can concentrate runoff, even on trails with low gradients. This can lead to gully erosion, especially if the rut breaks through the compacted tread surface to the less compacted subsoil.

Ruts can also result from pumping (Edwards 2011; Meyer 2002). Pumping occurs when the surface tread is dry but the subsurface is wet. The action of continuous traffic—such as during an event with a lot of traffic in a short time period—draws moisture to the surface, reducing soil strength. When the surface tread no longer has the strength to bear the traffic, vehicles break through the surface causing rutting. Rutting caused by pumping generally occurs on the flatter sections of trail that tend to hold moisture.

Wet Areas

Water can accumulate in flat areas and/or be perched close to the surface. Since wet soils have low strength, wet areas are subject to deep rutting. Extensive braiding can also occur when riders avoid deep ruts and seek firmer soils. Wet areas typically occur on soils high in clay, which dry out slowly.

Rutted Trail on Wet Clay Soils

Where infiltration from rainfall is the source of moisture in wet areas, soils can dry out between storms, although it may take some time. However, where wet areas have a perched water table, or are wet because of seepage, they can remain wet throughout most of the year.

Trails through broad wet areas often become widely braided and deeply rutted. Where possible, routes should avoid these areas. If there is no alternative but to cross a persistently wet area, techniques using rock, geotextiles, and other materials can be used to create a tread that can withstand wet weather traffic (Meyer 2002).

Potholes, Puddles, and Downed Logs

Water accumulates as puddles in low spots on trails. Most puddles on the SHMUT system occur in the sand over clay soils and have solid bottoms. Puddles can lead to trail widening by braiding where riders leave the trail to avoid them.

Puddles in Sand over Clay Soils

Except for trail widening, potholes and puddles are more of a nuisance than a threat to trail sustainability. Traffic through potholes can displace soil from the tread when muddy water is splashed onto the edge of the trail, but this soil is not lost from the site and can be reclaimed. In contrast, dust created by traffic on dry treads drifts far from the trail, and this soil cannot be reclaimed.

Downed logs across trails are also a cause of braiding and rutting. Undisturbed soils adjacent to trails are not compacted, and are highly susceptible to rutting when wet. The new routes riders create to get around downed logs are often deeply rutted.

Braiding at potholes and downed logs can be mitigated during trail maintenance. Downed logs can be cleared, and some potholes can be drained with hand tools. Some of this work is suitable for volunteer crews.

Tread Erosion

Tread erosion is the result of water concentration, which is caused by a lack of adequate drainage. Vehicle traffic is an indirect cause of tread erosion when it damages drainage structures to the extent that they no longer divert runoff from trails.

The impact of tread erosion is less obvious than damage by rutting. However, tread erosion can be more serious in the long term. Loss of tread can eventually lead to deeply entrenched trails that are no longer sustainable because they cannot be drained or have become too rough.

Braiding Caused by Downed Log

Sediment Delivery to Watercourses

New Bridge Crossing

Wet weather traffic at and near watercourse crossings—especially on the approaches to crossings—detaches soil from the tread. This soil is then readily transported as sediment to the watercourse. Properly designed watercourse crossings, such as bridges, mitigate the potential for sediment delivery at crossings.

Because many of the crossings in the area have been improved, some off-site impacts have already been mitigated. Several bridges have been improved or are scheduled to be improved. Although the primary reason for improving bridge crossings is to make the bridges more stable during large storm events, improvement of the crossing approaches during the bridge upgrade process significantly reduces sediment delivery.

MANAGEMENT TOOLS AND STRATEGIES

The potential for resource damage during wet weather use of trails depends on several factors. A trail manager has no control over the soil type or the precipitation. But trail location, trail layout and rolling dip spacing and design, watercourse crossing design, trail maintenance, and regulating traffic are all tools that can be used to manage the impacts of wet weather use. Note that closing trails is only one of several tools available to manage trails for wet weather use.

Trail Location

Location is important in several ways. Trails can be located—or relocated in the case of an existing system—to avoid soils that are chronically wet and have low strength. Some SHMUT system trails need to be rerouted, closed, and restored because the current location is not sustainable or because trail entrenchment has progressed too far.

Trail Layout and Design

Trail layout is important for many reasons, but especially for providing effective drainage. Proper layout can avoid long sustained gradients and trails down the fall line, and can incorporate breaks in grade to provide drainage. Layout also includes proper location and spacing of drainage structures (Parker 2004). Trail design may include special construction techniques for problem areas, such as chronically wet areas.

Watercourse Crossing Design

Paver Block Hardened Crossing

Properly designed crossings minimize the effects of wet weather use on water quality.

Crossing approaches have the highest potential for sediment delivery to watercourses. The approach is the segment of trail closest to the watercourse—more specifically, the segment of trail sloping toward the watercourse between the last waterbreak on the trail (the cut-off waterbreak) and the watercourse. Keeping the approach as short and as level as possible is the key to minimizing sediment delivery at watercourse crossings. The approaches to bridges and arch culverts are typically short and often include a reverse grade. In the SHMUT system crossings without structures typically have short approaches that are hardened with paver blocks.

Bridges, arch culverts, and hardened crossings have already been installed in the area, and several more are being upgraded.

Drainage and Trail Maintenance

The most important strategy in protecting native-surfaced trails from wet weather damage is providing effective drainage. Properly located crossdrains such as rolling dips disperse runoff before it concentrates and begins to erode the tread. A properly designed rolling dip (Poff 2006) incorporates a catch basin at the point where runoff is diverted from the trail. The catch basin traps the soil eroded from the tread and keeps it close to the trail. This allows maintenance crews to recycle captured soil back into the tread and drainage structure. Properly designed and located drainage structures minimize erosion, conserve soil by recycling it, and help keep treads drier so trails can be open longer.

Many segments of the SHMUT are in need of improved drainage. These segments may have been improperly designed, located, constructed, or maintained, overwhelmed by runoff, or damaged by traffic when wet. Some failures may be the result of a combination of these causes.

Catch Basin at Rolling Dip Outlet

Wet Weather Closures and Rainfall

The purpose of wet weather trail management is to avoid damage to trails and other resources. Protecting drainage structures from damage is the key to management of trails in wet weather. Closures based on precipitation are effective only to the extent that they protect drainage structures.

The amount of rainfall that makes rolling dips and treads susceptible to damage is affected by soil type, soil strength, antecedent rainfall, storm intensity and duration, rate and time of drying, and the amount and type of traffic. Because of all these variables, a direct correlation between rainfall and the potential for trail damage—especially to drainage structures—cannot be made for the SHMUT system. However, measurements of soil moisture and strength can be used to predict the potential for trail damage (Janicki 1998; Poff 2010). Detailed instructions on how to implement an evidence-based wet weather management policy are included in Appendices 1 and 2.

It is important to emphasize that closing trails is only one of many tools available to manage the effects of wet weather trail use. Implemented by itself, a closure will not protect trails or other resources from wet weather damage. Protecting trails from wet weather damage requires a fully integrated program of trail management.

Effective Management

All of the elements discussed above are important to maximize recreational opportunities in a sustainable manner while minimizing resource impacts. These tools and strategies complement one another and work synergistically as a total package. But effective management also includes signing, education, monitoring, trail maintenance, law enforcement, and organizing and mobilizing volunteer groups.

Managing a trail system is a full-time job. One of the most important characteristics —if not the most important—of an effectively managed trail system is the on-site presence of a manager whose primary responsibility is managing the trail system. This person is responsible for operation and maintenance of the trail system, including trailheads and staging areas, and for coordinating volunteer activities, coordination with engineering on drainage maintenance at road/trail intersections, and implementing the SHMUT Wet Weather Management Plan.

Methodology

DATA COLLECTION

Measurements of soil strength and soil moisture were made under wetting front conditions in September 2009 and under drying front conditions in January 2010. Measurements were made on the sand over clay soils and on the deep sandy soils under both wetting and drying fronts. In April 2012 additional measurements of moisture were made to calibrate the HH150 moisture meter to the threshold values. Details on measuring soil strength and soil moisture are in Appendix A-2.

Wetting and Drying Fronts

In a wetting front the tread is wet or moist at the surface, but dry below. This occurs when the top few inches of the tread have been wetted up by a recent storm. On the Sam Houston NF, this typically occurs during the summer months when evapotranspiration is high. Trails dry out between storms by surface evaporation, gravity, evapotranspiration (where roots are present), and absorption by the dryer soil below. The dry subsoil has good bearing strength, so damage is usually limited to an inch or less of the surface tread. The risk of tread damage is generally low under a wetting front.

In a drying front the tread is dry at the surface, but wet or moist below. This occurs during the winter rainy season when evapotranspiration is low. Drying occurs slowly because the wet subsoil constantly replenishes the moisture lost by drying at the surface, and because there is little evapotranspiration. If the dry surface layer is too thin or weak, traffic breaks through, creating deep ruts. Also, heavy traffic can “pump” subsurface moisture to the surface (Meyer 2002). This weakens the running surface allowing traffic to break through it. The risk of tread damage is high under a drying front.

Generally, the time after a storm that trails need to be closed is longer under a drying front than under a wetting front.

Field Measurements

Trail segments were selected to include a variety of moisture and strength conditions. A motorcycle was then driven up and down the segment 10 to 12 times to simulate normal traffic. This created varying degrees of damage to rolling dip structures and treads. Measurements of soil strength and moisture were then made at each drainage structure in the segment. Strength was measured with a proving ring cone penetrometer; soil moisture was measured with a tensiometer and an electronic soil moisture sensor. Evidence of tread damage was observed using rut shape (Lull 1959; Poff 1999; Halvorson et al. 2001) as a guide as shown in Figure 1.

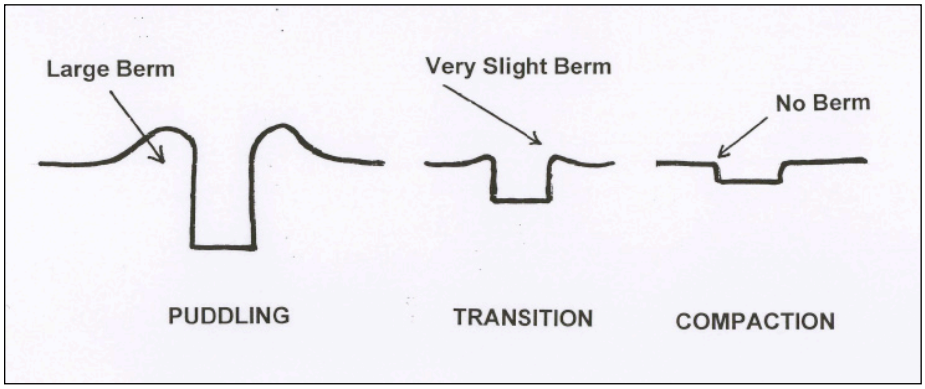

Figure 1. Rut Shape and Tread Failure

Condition was recorded as good, moderate, or poor based on the evidence of compaction and puddling. The points sampled within the rolling dip structures are shown in Figure 2.

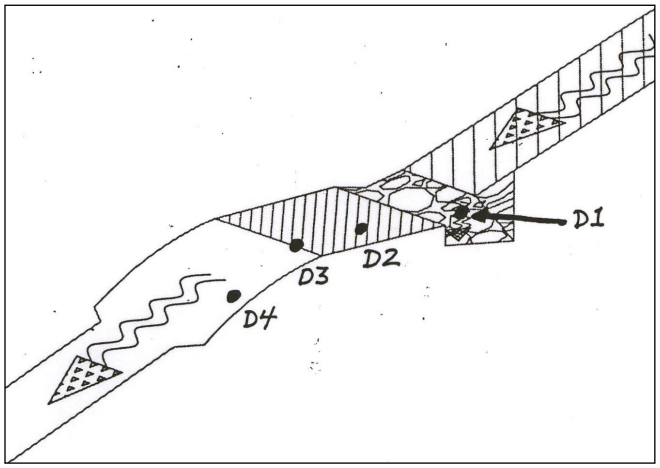

Figure 2. Location of Sampling Points in Rolling Dip Structures

Measurements were made at 248 data points at rolling dip structures. This included 140 points in a wetting front and 108 points in a drying front. A total of 116 data points were measured on deep sandy soils, 44 points on clay soils, and 88 points on sand over clay soils.

DATA ANALYSIS

The measurements of soil strength and moisture and the observations of tread damage were analyzed to determine when traffic began to cause puddling, or displacement, rather than compaction. This is the threshold (in terms of soil strength and moisture) at which the risk of trail damage becomes high. Thresholds were determined by plotting soil strength (psi) and soil moisture (millibars and percent moisture) against observed soil condition. This analysis was done for various combinations of soil type, wetting/drying fronts, and rolling dip position. Because so much data was collected, many plots of the data were required to determine the threshold values.

Results and Discussion

ROLLING DIP FAILURE

One of the most significant observations made while collecting the field data, was how rolling dips fail when they are too wet. The original hypothesis was that, under wet conditions, traffic would cut a rut into the top, or crest, of the rolling dip structure. However, it was discovered that the rolling dip structures fail when traffic creates ruts in the rolling dip outlet, which then causes rutting into the first shoulder coming out of the dip (position D2 in Figure 1).

Sequence of Failure

The dips appear to fail in this sequence: (1) water ponded at the bottom of the dip reduces bearing strength; (2) traffic cuts a rut into the bottom of the dip; (3) the rut steepens the angle of the exit shoulder coming out of the dip, creating a concave profile, and causing traffic to cut into the shoulder. This is shown in Figure 3.

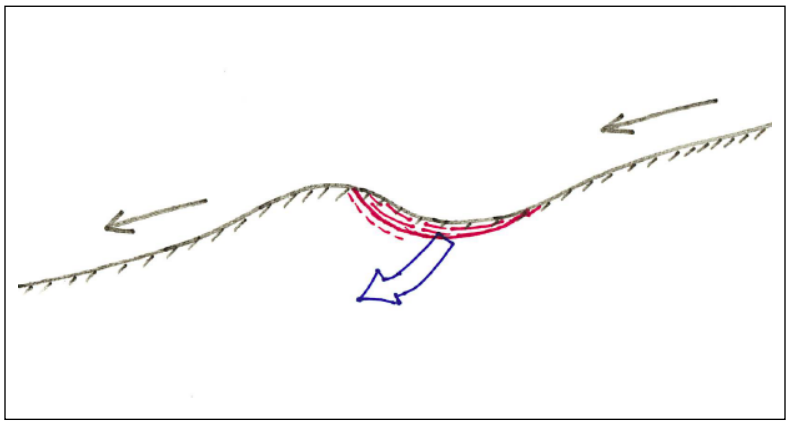

Figure 3. Wear Pattern on Rolling Dip Structure

This wear process is accelerated where dip structures have a short and steep shoulder. Dips constructed with a longer and more convex exit shoulder are less susceptible to this wear pattern. This wear process is caused primarily by downhill traffic. Uphill traffic can also cause rutting on the shoulder downhill of the crest, but this is less common, and usually occurs where the shoulder is short and steep.

Dip Design and Maintenance

Rolling dip design and maintenance both affect how susceptible the drainage structures are to failure. There are two design factors. The first is the length of the dip structure. Lengthening the distance from the dip outlet to the crest of the structure by as little as two or three feet can create a longer and more convex shoulder exiting the dip. The second design component is the degree of outsloping in the bottom of the dip. When the outslope at the bottom of the dip is less than about 3%, water tends to pond at the outlet, increasing the risk of failure.

The maintenance factor is keeping the dip outlets open and free to drain. Regular maintenance with a rock rake to pull in the small berm that develops at the dip outlet can help keep the outlet open and free to drain.

In the deep sandy soils, rolling dips did not appear to fail by this process. The mechanism for failure on the deep sands appeared to be related to the increased traction sands have when wet. This traction causes tires to dig into the second shoulder of the rolling dip structure and into the crest of the structure.

It should be noted that this process of rolling dip failure, while not unique to the SHMUT system, might not occur in other situations where soils and types of OHV traffic are different.

DATA VARIABILITY

At the start of the data collection the best positions to sample on the rolling dip structures were unknown, so multiple sampling points were measured to determine the best locations. But this generated a large amount of data, and the variability in the data made it difficult to correlate tread failure with moisture and strength. Some of the reasons for this variability are discussed below.

Tread Condition Classes

Tread condition was recorded in only three classes: good, moderate, and poor. Five condition classes could have been observed consistently and would have allowed a more precise analysis of the data.

Operator Error Using the Penetrometer

The penetrometer measurements were quite variable, and were partially dependent on the operator. Volunteers and Forest Service employees made many of the measurements as a training exercise, which also contributed to the variability. Soil strength readings made with the penetrometer were more consistent when made by one individual.

Tensiometer

The tensiometer took a long time to equilibrate so a reading could be taken. In the heavier clay soils, this was as long as 15 minutes. Because of the long equilibration times, fewer moisture measurements were made. Only one or two moisture measurements were taken at most rolling dip structures. This may not have been enough to capture the actual variability in moisture. Also, the tensiometer is more sensitive at higher moisture tensions, but less sensitive near field capacity or saturation, and this is the moisture level at which failure begins to occur.

HH150 Moisture Meter

The HH150 soil moisture meter used for the April 2012 moisture measurements resolved many of the problems with the tensiometer. Moisture readings with the HH150 are instantaneous, allowing multiple readings to be taken quickly. Also, the HH150 is more sensitive at moisture levels near field capacity and saturation, the moisture levels near the threshold of failure. The HH150 is also much simpler to use and is less susceptible to operator error. The only downside is that the sensor rods are somewhat fragile and do not readily penetrate dry soils. But when soils are so dry that this is a problem, soil moisture is well below the threshold of failure. In dry soils a penetrometer can be used to document the tread condition.

THRESHOLD VALUES

The thresholds established using this methodology provide a scientific basis for wet weather management of the SHMUT system. Allowing OHV traffic when these values are exceeded means there is a moderate to high risk of damaging drainage structures or treads. The thresholds developed for the SHMUT system are shown in Table 1. How these thresholds are used to determine when to open and close trails is described in Appendix A–1.

Soil Type	Deep Sands	Sand over Clay	Clay
Soil Moisture Content (% by volume)	38.0	40.0	42.0
Soil Moisture Tension (cb)	5.0	6.0	7.0
Soil Strength (psi or C.I.)	100		
Soil Strength (deflection)*	180		

Table 1. Threshold Values of Soil Moisture and Soil Strength for the SHMUT

* Deflection values are provided for using the Humboldt H4204 proving ring cone penetrometer equipped with a 0.5-inch tip, the penetrometer used on the Sam Houston NF.

VOLUNTEER INVOLVEMENT

The importance of involving volunteers and trail users cannot be underestimated. Involving the volunteers in the initial data collection did add to the variability of the data collected, but this was offset by the understanding and trust that was built through their participation. The

volunteers found the whole process interesting and they took ownership in it. This created an environment for acceptance.

MANAGEMENT AREAS

Portions of the SHMUT system occur on different soil types that respond differently to traffic when soils are wet. There is a potential to open and close these areas independently. This would require installing several gates and some signs, and rerouting some trails. This may be done at some time in the future, but for the present the preference is to open and close the whole trail system as a unit.

REMOTE SENSING

The technology to measure soil moisture and rainfall remotely is currently available (Kees and Trent 2005). However, there are several reasons why this is not recommended. It is the moisture in the trail tread itself that affects trafficability. This means moisture sensors would have to be installed in the trail tread, specifically just below the tread surface. This would make the sensors vulnerable to damage by traffic, and they would need to be replaced during trail maintenance. Locating the sensors at the edge or off the trail is not a viable solution because compacted treads absorb moisture and dry out at different rates than undisturbed soils. Moisture data collected off-trail would have to be calibrated with tread moisture over a period of time to be useful. Also, the solar panels and radio towers needed to transmit data remotely would be vulnerable to vandalism. Finally, there is no substitute for getting out in the field to observe actual trail conditions. In the SHMUT system, the benchmark sites for measuring soil moisture and strength are located only a few minutes from the office. For these reasons, it is difficult to make a case for remote sensing of soil moisture, at least for the SHMUT system.

APPLICATION TO OTHER AREAS

The process used to develop the thresholds for opening and closing trails is empirical, i.e., based on on-site measurements, and therefore must be developed for each area. Soil types and patterns, amount and type of traffic, vegetation and drying conditions, and the layout of the trail system itself all affect threshold values, and vary from place to place. For these reasons, the thresholds established for the SHMUT system cannot be applied directly to other OHV areas.

That being said, the thresholds of moisture and strength developed for the SHMUT system are similar to those observed in other locations. Threshold values measured on the Stanislaus National Forest, the Ouachita National Forest, and the Los Padres National Forest are close to those developed for the SHMUT system.

Although the process of developing thresholds of risk for wet weather management is relatively straightforward, help from a professional familiar with wet weather trail management is recommended when developing a management strategy using these techniques. Every OHV area is unique, and there are many variables that could easily be overlooked.

Recommendations

Some of the tools and strategies discussed in this report have already been implemented; some can be implemented immediately; some will require more time to develop; and some will have to be part of a long-term (3 to 5 year) strategy to redesign the trail system. Actions can be grouped into six steps in order of priority:

- Clear out downfall and drain potholes.
- Assess trail condition and take appropriate action to address drainage needs.
- Continue to upgrade watercourse crossings.

- Implement the evidence-based wet weather management policy described in this report.
- Schedule long-term rerouting and restoration, and protect existing infrastructure.
- Monitor the implementation and effectiveness of the wet weather management policy; trail condition; and long-term trends.

Clear Out Downfall, and Drain Potholes

This would eliminate the two major causes of braiding and rutting. It would also reduce the visual impact of wet weather damage. Volunteers could clear trails of downfall and could drain some of the smaller potholes. Mechanized equipment would be needed to drain many of the larger potholes, but this could be done as part of redesign and maintenance.

It should be emphasized that the effects of downfall and potholes on trail widening are a less serious threat to trail sustainability than the lack of effective drainage structures.

Assess Trail Condition, and Take Appropriate Action to Address Drainage Needs

The first step is to identify and correct problems where runoff from roads is being diverted onto trails. The top priority sites are those where treatment can prevent additional erosion. Some sites are already so damaged that they will have to be relocated and restored.

After the most critical sites have been properly drained, effective drainage should be reestablished on all trails. Some of this work has already begun.

Continue to Upgrade Watercourse Crossings

This is already in progress, both as bridge replacements and with arch culverts. Many of the smaller channels that now have hardened approaches could be upgraded with arch culverts.

Implement the Evidence-based Wet Weather Management Policy Described in This Report

The wet weather management plan in Appendix A-1 has been developed specifically for the SHUMT system.

Schedule Long-term Rerouting and Restoration, and Protect Existing Infrastructure

Some SHMUT system routes are in unsustainable locations, and some are so deeply entrenched they cannot be drained effectively. Long-term, they will need to be rerouted, closed, and restored. The first step is to identify these segments and rank them by priority for treatment.

Some of the trail infrastructure (arch crossings, bridges, trails) is threatened by gully headcuts that are migrating upstream. Long-term, the headcuts will need stabilization to protect the trail system.

Monitor the Implementation and Effectiveness of the Wet Weather Management Policy, Trail Condition, and Long-term Trends

Management of a trail system is not static. Types and amounts of use change over time. The environment also changes over time. In the SHMUT area, for example, vegetative cover is changing as thinning and underburning are used to manage wildlife habitat. The benchmark sites, threshold values, and management tools suitable for today may not be appropriate in the future. As the SHMUT system is improved, and is allowed to be open for longer periods, the level of use is likely to increase. All of this creates a need for monitoring and adaptive management.

Five types of monitoring are needed to evaluate the effectiveness of wet weather trail management for the SHMUT system: (1) implementation monitoring; (2) effectiveness

monitoring; (3) validation of the criteria used for closures; (4) trail condition monitoring; and (5) monitoring for long-term trends.

Implementation Monitoring

This is simply documenting whether or not the wet weather management plan was used as described. It answers the question: “Was the plan used as described?”

Effectiveness Monitoring

This is evaluating how well the wet weather management plan worked—whether it met its objectives. It answers the question: “Did the plan protect the rolling dips and trail tread from damage while at the same time maximizing opportunities for recreation?”

Validation Monitoring

Validation monitoring verifies the threshold values used to trigger opening and closing trails. The threshold values for opening and closing trails need to be tested over time. The best way to do this is to measure soil strength and moisture and observe the actual effects of traffic when trails are opened based on the threshold values, especially when moisture is near the threshold value.

Trail Condition Monitoring

Trail condition monitoring identifies trails that need maintenance (CA State Parks 2008). Normally, monitoring trail condition would not be considered part of wet weather management. However, given the current condition of the SHMUT system, an assessment of condition is needed to identify trail segments that need to be maintained to a condition that can withstand wet weather use.

Long-Term Trend Monitoring

Long-term trend monitoring is also needed to insure that the SHMUT system is sustainable. The purpose of trend monitoring is to track how the whole system changes over time. Randomly located permanent photo points are ideal for this (Hall 2002a, 2002b). This monitoring is relatively simple and inexpensive to implement and maintain. The randomly selected photo points occur on stable trail segments as well as on changing segments, and provide an accurate assessment of the trail system as a whole.

Feedback and Action

Monitoring accomplishes little unless the results are reviewed and actually used to make decisions and take action. Taking action includes continuing on the present course as well as making needed changes.

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Appendix

A-1 AN EVIDENCE-BASED PROCESS FOR WET WEATHER MANAGEMENT OF THE SHMUT SYSTEM

A-2 TRAFFICABILITY ASSESSMENT

Appendix 1 - An Evidence-based Process for Wet Weather Closures on the SHMUT

Introduction

Wet weather closures of SHMUT trails based on rainfall have not been effective for reasons discussed elsewhere in this report. The closure method described in this Appendix is based on a correlation of soil moisture and soil strength with observed damage to OHV trails.

The process includes six elements:

1. *Threshold values* are measurements of soil strength, moisture, or moisture tension to determine trafficability. When threshold values are exceeded, the risk of damage to trails is moderate to high.
2. *Benchmark sites* are representative locations where soil strength and moisture are measured to determine whether or not the threshold values are exceeded.
3. *Protocols for measurement* describe specifically how the measurements of soil strength and moisture are taken and how these measurements are used to determine whether the benchmark site exceeds the threshold.
4. *Decision tree* is a flowchart that specifies when the benchmark sites are to be measured and when the trails are to be closed or opened.
5. *Documentation* of field measurements, calculations, and decisions to open or close trails is made on a standardized form. Completed forms can be used as part of an implementation and effectiveness *monitoring* program.
6. *Forest Order* A legal document signed by the Forest Supervisor that specifies the conditions under which trails will be opened or closed and penalties for violations of the closure.

Threshold Values

Threshold values of soil moisture and soil strength have been established for soil types on the SHMUT system. These values are based on measurements and observations made on SHMUT system trails. Threshold values are shown in Table 1. When these threshold values are exceeded, the risk of failure from OHV traffic is moderate to high.

Measurement Type	Threshold
Soil Moisture Content (% by volume)	> 40.0
Soil Moisture Tension (cb)	< 6.0
Soil Strength (psi or C.I.)	< 100
Soil Strength (deflection)[1]	< 180

Table 1. Threshold Values of Soil Moisture and Soil Strength for the SHMUT System[2]

1 Deflection values are provided for use of the Humboldt H4204 proving ring cone penetrometer equipped with a 0.5-inch tip.

2 Measurements above the threshold for moisture content, or below the thresholds for soil strength and for moisture tension, have a moderate to high risk of damage to drainage structures and trail treads with OHV traffic.

Benchmark Sites

Five benchmark sites at rolling dip structures representative of the SHMUT trail system have been selected for monitoring. When *two or more* of the five benchmarks exceed the threshold values, the trail system will be closed or will remain closed. If only one of the five benchmarks exceeds the threshold, the trail system will be opened or will remain open to use.

The five benchmark sites are located on Trail 813 just north of the East Trailhead at rolling dips in the following locations:

OBJECTID *	SHAPE *	Nearest_TH	Name	X	Y
26	Point	233	813-8	3494055	352979
34	Point	233	813-03	3493966	353163
35	Point	233	813-04	3493975	353122
36	Point	233	813-05	3494034	353041
37	Point	233	813-06	3494065	352910

Protocols for Measurement

At each of the five benchmark sites, three (3) measurements of soil moisture content shall be taken in the rolling dip outlet (D1 in Figure 1), and three (3) measurements shall be taken on the first shoulder (D2 in Figure 1) of the dip (see diagram). Measurements shall be taken within the 1/3 of the trail tread on the dip outlet side of the trail.

An average of the three readings for the dip outlet and for the shoulder shall be used to determine whether the benchmark site exceeds the threshold. If the average for *either set* of three readings (for the dip outlet or the dip shoulder) exceeds the threshold, the benchmark site exceeds the threshold.

Measurements shall be taken in the 0-3 inch layer of the tread surface. For the HH150, scrape away the top 1/2-inch of soil before inserting the moisture probe. If the soil is too firm to insert the moisture probe without the risk of damage to the instrument, measure the soil strength of the 0-3 inch zone with a penetrometer.

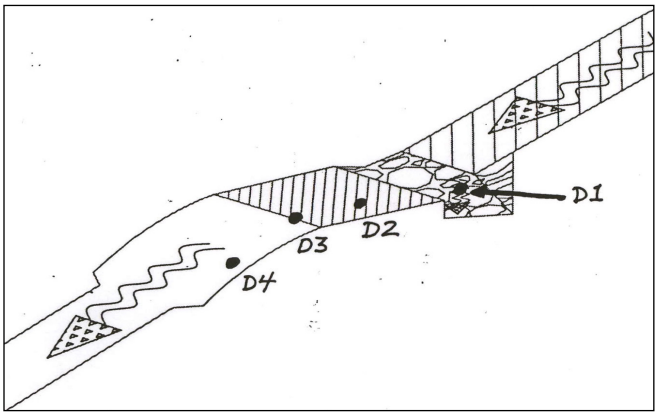
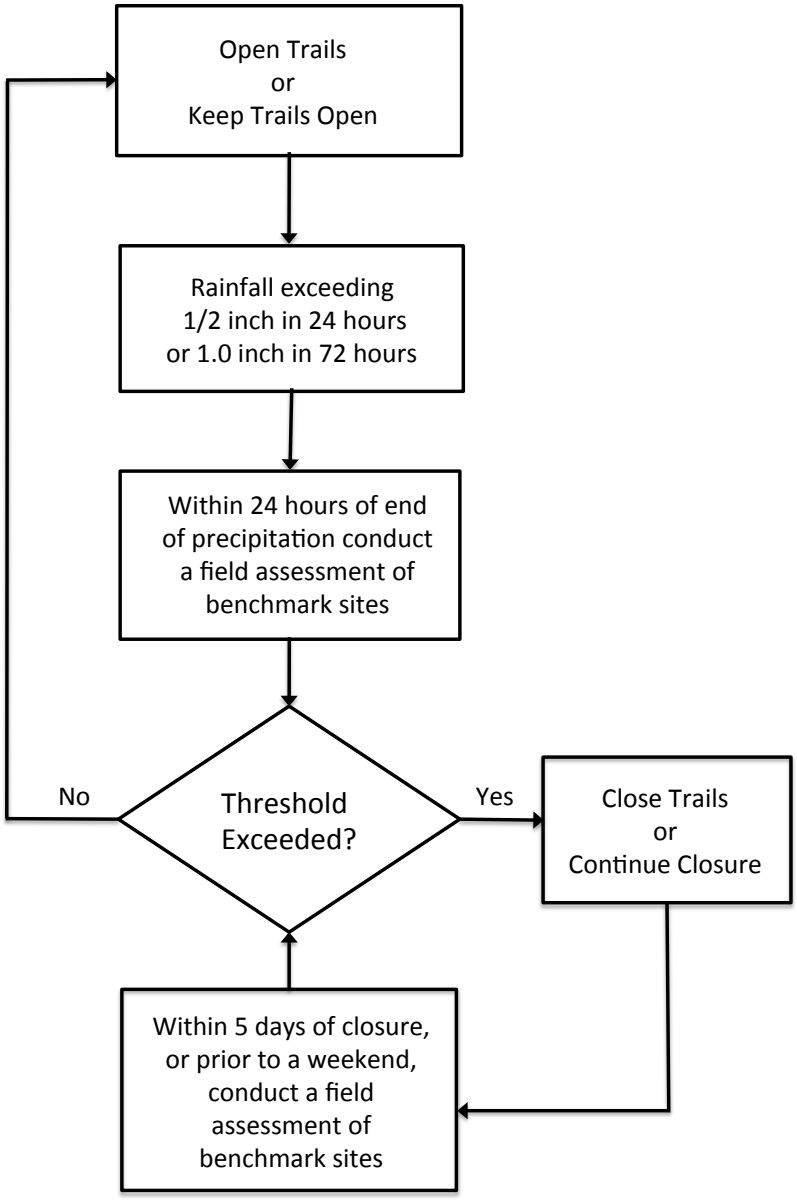


Figure 1. Rolling Dip Showing Sample Locations

Decision Tree

The decision tree flowchart below (Figure 2) shows when measurements of soil strength and moisture shall be taken, and how the threshold values at the benchmark sites affect decisions to open and close trails.

Figure 2. Decision Tree for SHMUT Trail Closures



SAM HOUSTON NATIONAL FOREST
Montgomery and Walker Counties, Texas

Wet Weather Trail Closures

Forest Supervisor Order No. xx-xx-xx-xx-xx
National Forest System Trail Closures

Pursuant to the authorities in 36 CFR Part 261.50 (b), and to prevent damage to the Multiple-Use Trails listed below, I am closing the trails listed below during periods of excessive soil moisture:

Mutiple-Use Trails subject to closure:

MUT813	MUT818
MUT814	MUT819
MUT815	MUT820
MUT816	MUT821
MUT817	

Prohibited Acts: Being on any of the above trails when they are closed pursuant to the conditions listed in the approved Wet Weather Management Plan for Multiple-Use Trails. **36 CFR Part 261.55(a)**

Effective Date: This Order is effective (*Insert Date*) and continues until rescinded. All or a portion of the trails listed above may be closed when the conditions specified in the Wet Weather Management Plan are met, and shall remain closed until those conditions are no longer present.

Public Notification: Due to the intermittent nature of trail closures as a result of the Wet Weather Management Plan for Multiple-Use Tails, this order is not effective until the following public notifications actions have been completed: **Affected trails will be posted as closed at Trailheads serving the Multiple-Use Trail system and listed as closed on the National Forests and Grasslands in Texas website** (http://www.fs.usda.gov/detail/texas/home/).

Pursuant to 36 CFR 261.50(e), the following persons are exempt from this order:

1. Forest Service employees in the performance of their official duties;

2. Persons with a permit specifically authorizing the otherwise prohibited act or omission;

3. Any Federal, State or local Law Enforcement Officer, or member of an organized rescue or fire fighting force in the performance of an official duty; and

4. Emergency crews who are repairing or restoring utility services; .

These prohibitions are in addition to the general prohibitions listed in Title 36 CFR, part 261, Subpart A and to other prohibitions which may be in effect within the same area as listed in Title 36 CFR, part 261, subpart B.

Executed in Lufkin, Texas this _____ day of _____, 20xx.

_____

Stephanie Neal Johnson
Acting Forest Supervisor
National Forests and Grasslands in Texas
Forest Service, USDA
2221 North Raguet
Lufkin, Texas 75904

Violation of these prohibitions is punishable by a fine of not more than $5,000 for an individual and $10,000 for an organization, inprisonment for not more than six (6) months , or both (16 U.S.C. 551 and 18 U.S. C. 3559 and 3571).

Documentation and Monitoring

Field measurements, calculations, and observations of trail conditions shall be documented on the following standardized form.

The completed forms shall be reviewed annually as part of monitoring the implementation and effectiveness of the closure policy.

Documentation of Field Assessment for SHMUT Trail Closure/Opening

Trail		Date		By
Rainfall		Drying Conditions		
Site / Reading	Moisture		Strength (optional)	
	Outlet	Shoulder	Outlet	Shoulder
1-1				
1-2				
1-3				
Average				
Exceeds Threshold	Yes / No	Yes / No	Yes / No	Yes / No
Site Exceeds Threshold	Yes / No			
2-1				
2-2				
2-3				
Average				
Exceeds Threshold	Yes / No	Yes / No	Yes / No	Yes / No
Site Exceeds Threshold	Yes / No			
3-1				
3-2				
3-3				
Average				
Exceeds Threshold	Yes / No	Yes / No	Yes / No	Yes / No
Site Exceeds Threshold	Yes / No			
4-1				
4-2				
4-3				
Average				
Exceeds Threshold	Yes / No	Yes / No	Yes / No	Yes / No
Site Exceeds Threshold	Yes / No			
5-1				
5-2				
5-3				
Average				
Exceeds Threshold	Yes / No	Yes / No	Yes / No	Yes / No
Site Exceeds Threshold	Yes / No			

Notes on Trail Conditions:	
Decision: Open / Close	Approval

Appendix 2 - Trafficability Assessment

Introduction

Trafficability can be used to predict the risk of damage to OHV trails under wet conditions. This Appendix describes a method for assessing trafficability on native surface trails using a penetrometer and a tensiometer or moisture meter. The method is based on three variables: soil strength, soil moisture, and trail response to traffic. Trafficability is a more direct and reliable method than rainfall for predicting the risk of trail damage.

Soil strength and moisture are interdependent. As soil moisture increases, soil strength decreases. This method uses measurements of both soil strength and soil moisture. The measurements of strength are more sensitive at the drier end of the moisture range, while the measurements of moisture are more sensitive at the wetter end of the range, where trail damage occurs.

Soil moisture is measured using either a 2900F1 Quick Draw Soil Moisture Probe (tensiometer) or a Delta T HH150 with SM150 sensor (moisture meter). Soil strength is measured using a Humboldt H-4204 Proving Ring Cone Penetrometer.[1] The response to traffic is based on observations of damage to trail treads, such as rutting, displacement (puddling), or compaction.

The Process

The Method involves several steps:

- Collecting data on soil strength, moisture, and trail condition;
- Developing predictive curves that correlate soil moisture and soil strength with the relative risk of trail damage;
- Using the predictive curves to develop thresholds for opening or closing trails;
- Selecting benchmark sites for monitoring.

Data Collection

Locate several trail segments containing drainage structures in a variety of soil moisture states. The trail segments should include enough wet soils so that normal OHV traffic will cause some damage to the drainage structures. Suitable conditions could occur during the wet season or just after a storm, when the area is closed or would normally be closed. Alternatively, trail segments could be artificially wetted up to create a variety of soil moisture conditions.

Allow OHV Traffic to Create Some Damage

After locating—or preparing—suitable trail segments, drive an OHV back and forth on the trail to simulate normal riding conditions. To simulate normal use, eight to twelve passes are usually sufficient to cause enough tread failure for sampling. The objective is to generate a range of sample sites, including some that have been damaged by traffic, some on the verge of being

[1] On the SHMUT the penetrometer has been modified to use a ½-inch 30º cone as used by the Corps of Engineers.

damaged, and some that have no damage. Alternatively, observations can be made on trails damaged by normal traffic because the trails were open when conditions were too wet.

Locate Sample Points Along the Trail

Walk the trail and locate sample sites for taking the measurements and observations. Make observations and measurements on at least 12 sample points. A total of 25 to 30 sample points is ideal. Repeat the process for each major soil type in the trail system.

Measurements and Observations[2]

Collect data at four points in drainage structures as shown in Figure 1:

- At the rolling dip outlet (D1);
- On the shoulder of the rolling dip on the outlet side (D2);
- On the rolling dip crest (D3); and
- On the shoulder of the dip, on the downhill side (D4).

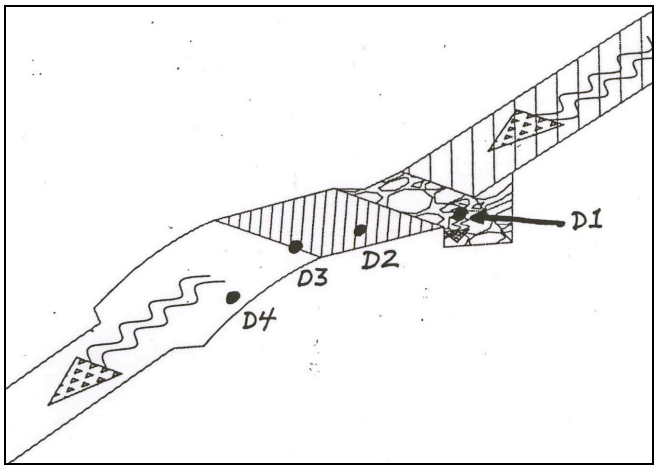


Figure 1.

Measure strength and moisture as close as possible to the vehicle tracks where the trail condition is observed.

Soil Moisture

If using the tensiometer, measure soil moisture at D1 and at D3. Record soil moisture in centibars (cb) of suction. The tensiometer dial reads directly in centibars of suction.

If using the HH150 Moisture Meter, measure soil moisture at all four sites. The HH150 reads percent volumetric moisture directly. Because readings are instantaneous, three readings at each of the four sites may be taken to improve accuracy, if desired.

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[2] When making measurements for the initial calibration, take the measurements just to the side of the observed vehicle tracks, in areas that have not been damaged by traffic.

Soil Strength

Measure soil strength with the penetrometer. Take three readings at each of the four sample points. Record soil strength as cone index (ci). When equipped with a 1/2-inch cone, the penetrometer dial reads cone index directly.

Tread Condition

Observe vehicle tracks at each of the four sample points. Record tread condition as: *good* (G), *marginal* (M), or *poor* (P).[3] Good means the tracks show no evidence of failure or tread damage; marginal means tracks in the tread show evidence of being near the transition from compaction to puddling; and poor means that the soil was wet enough to fail, as indicated by puddled and/or rutted tracks.

Deep ruts with berms indicate puddling. Where soil is puddled, the volume of soil in the berm is roughly equal to the volume of the rut. Compaction is indicated by shallow tracks with sharp edges and no berms. Tracks or ruts with very slight berms indicate both compaction and puddling have occurred. See Figure 2.

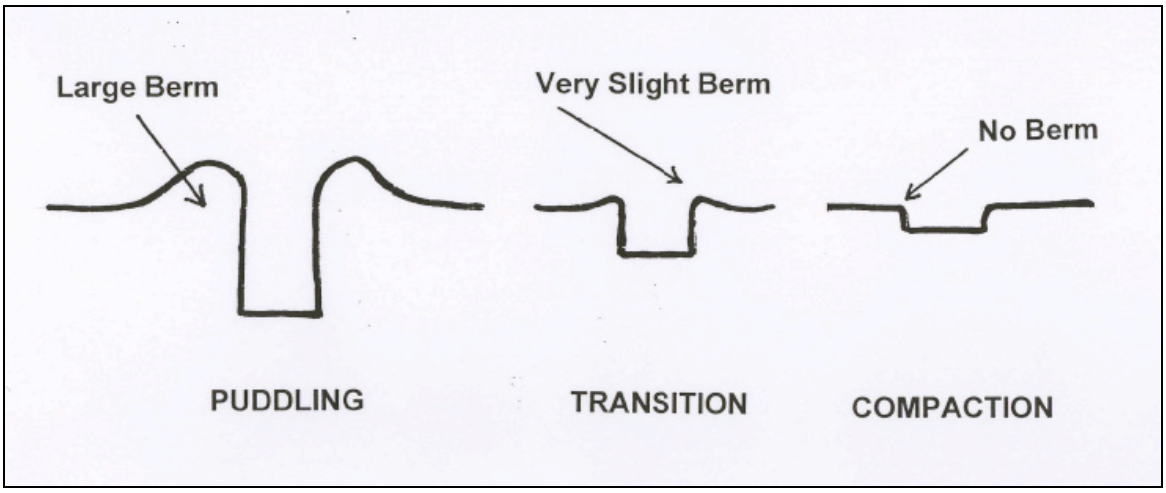

Figure 2.

Measurement Depth

Take all measurements at a 3-inch depth. For the tensiometer, this means coring a sample hole approximately 3-1/2 inches deep. For the HH150 Moisture Meter this means excavating a small hole 1/2-inch deep and inserting the sensor rods into the soil at the bottom of the hole. For the penetrometer, this means inserting the penetrometer to a depth of 3 inches above the top of the cone tip.

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[3] On the SHMUT, it was found that five classes of disturbance could easily be recognized. Using five classes will give a tighter data set and more precise predictive curves.

Data Form

Record the data and observations for each sample point on the data form provided at the end of this Appendix.

Create Relative Risk Curves and Thresholds

For each soil type sampled, plot the data points on a scatter diagram (Figure 4 is an example). *Increasing* soil strength is plotted on the y-axis as cone index (ci); *decreasing* soil moisture is plotted on the x-axis as centibars of suction (cb) if using the tensiometer, or as percent moisture (%) if using the HH150 Moisture Meter. Use different symbols (triangle, circle, square) or colors to plot observations of good, marginal or poor trail condition.

After the data have been plotted on the scatter diagram, curves can be hand-drawn (or computer generated) to indicate conditions under which the relative risk of trail damage is *low*, *borderline*, or *high.* The curves can be used to develop threshold values of strength and moisture, and to determine which sampling points (D1, D2, D3, or D4) provide the best prediction of failure.

Locate Benchmark Sites

After the relative risk curves for each soil have been developed, the curves can be used to predict when trails can be opened with a low risk of damage, or when they should be closed to avoid damage. However, a key link in the process is locating representative or benchmark sites to monitor. Benchmark sites should be representative of the whole trail system, and should also be readily accessible. Because conditions within a trail system vary from place to place, selecting benchmark sites is a critical step in the process.

Using the Tensiometer (2900F1 Quick Draw Probe)

Components of the tensiometer are shown in Figure 3.

Testing the Tensiometer

The porous tip and the tensiometer are working correctly when—after turning the null knob *counterclockwise* until the dial reads 50 cb—turning the null knob *clockwise* allows the needle to drop back to zero in one or two seconds. If the needle does not drop rapidly back to zero, the tensiometer needs to be recharged or the porous tip needs to be cleaned or replaced. Details are given in the full operating instructions for the tensiometer.

Taking Soil Moisture Measurements

Begin with a fully charged tensiometer. While the tensiometer is still in its case, turn the null knob all the way in (clockwise), and then turn the knob counterclockwise about a half turn. This will put the instrument in a suitable range for readings. If the porous tip has been kept moist, and the tensiometer is fully charged, the dial should rise to about 20-30 cb, and then quickly drop back to zero. If it does not, the tensiometer needs to be cleaned and/or recharged.

Using the coring tool, core a hole 3-1/2 inches deep. This will put the porous tip at 3 inches when the probe is inserted. When coring, keep the corer as vertical as possible. If the tensiometer stem is not vertical, friction on the very thin column of water in the stem will affect the readings.

Remove the tensiometer from its case, and (if soils are nearly saturated or are heavy clays) very lightly dry off the excess moisture on the porous tip before inserting the stem into the sample hole. If the soil is already near saturation, excess water on the porous tip will increase the time it takes for the tip and the soil to reach equilibrium. Before reading the dial, allow about 10-15 minutes for the porous tip to reach equilibrium with the moisture in the soil.

Alternatively, readings can be obtained more quickly using the null knob to bracket the readings. Bracketing does not work well on heavy clay soils (because soil moisture moves very slowly through them), but bracketing may give quicker readings in dry or sandy soils. Use the null knob as follows:

> After inserting the tensiometer into the soil, let the needle rise for one or two minutes. Make a mental note of this first reading. Then turn the null knob counterclockwise until the dial reaches a value about 1.5 times higher than the initial reading. After 30 seconds, observe the needle movement. If the needle is moving down, turn the null knob clockwise until the dial drops to a value half way between the initial reading and the second reading. Observe the movement of the needle again, and then repeat the bracketing process until a stable reading is achieved.
>
> If the needle is still moving up after the null knob has been turned counterclockwise to 1.5 times the initial reading, turn the null knob counterclockwise again to raise the needle 10 more points on the dial. If the needle is still moving up, continue to add 10 points at a time until the needle begins to move down after waiting 30 seconds. Then bracket downwards as described above.

Although bracketing is useful, and can work well on sandy or dry soils, being patient and allowing 10-15 minutes for the porous tip and soil to equilibrate will give more accurate readings.

After taking the readings, and before reinserting the tensiometer into its case, gently wash the porous tip with a squirt bottle to remove any soil on it. This is important in heavy clay soils, which tend to clog the porous tip. Washing off the tip will also help keep the sponge in the case clean. Under very hot or very dry conditions, frequently add water to the sponge in the carrying case to keep the porous tip wet.

Using the HH150 Moisture Meter with SM150 Moisture Sensor

The HH150 Moisture Meter with SM150 Moisture Sensor is very simple to set up and use, and provides quick and highly accurate moisture readings. However, some care is required in its use, particularly in avoiding damage to the sensor rods. Photos of the HH150 are attached.

Set Up

Insert the batteries. Use only good quality *alkaline* batteries. Remove the batteries when the meter will not be in use for an extended time period. Connect the SM150 sensor to the HH150 meter. Align connectors carefully before pushing the parts together. Screw together firmly.

With the meter OFF, press the *right* **off-menu** button. This wakes the meter and allows you to set the display readings. Set to *% volumetric water content* and to *mineral soil*. Then press **off** to save the current setting and turn the meter off. This is a one-time step unless the batteries are removed. If set up correctly, the moisture readout will show “mineral” and “% vol.”

Taking Readings

Clear away any stones and excavate a small hole 1/2-inch deep, and a little larger than the sensor diameter (about 45mm). Make sure the bottom of the hole has a reasonably flat surface.

Push the SM150 rods into the soil until the rods are fully inserted. Insure good soil contact. Insert the rods slowly; if resistance is felt you have probably hit a stone or pebble. Stop and re-insert at a new location. Avoid pressure that will change the rod alignment. If the site is too dry and hard to insert the rods, the site is well under the moisture threshold, anyhow. Just document the condition with a penetrometer reading.

With the meter OFF, press the *left* **on-read** button to take a reading. The reading will be instantaneous. The meter will sleep after about 30 seconds.

Care and Safety

- The sensor rods of the SM150 are very sharp to ease insertion. They can puncture skin, so care is advised.
- Do not touch the sensor rods or expose them to other sources of *static charge*, particularly when powered up or attached to the cable. An electrostatic discharge from your body can typically cause a temporary -10mV offset in sensor readings for up to one hour. Worst case, it could even permanently damage the sensor.
- Do not pull the SM150 out of the soil by its cable.

Using the Proving Ring Penetrometer (Humboldt H-4204)

Components of the penetrometer are shown in Figure 3.

Penetrometer Adjustments and Maintenance

If treated carefully, as with any fine instrument, the proving ring penetrometer should require little maintenance or adjustment. Before using the penetrometer, check to see that the plunger at the base of the dial is in contact with the adjustment nut at the bottom of the proving ring (see Figure 3). This can be done several ways. The easiest is to hold the penetrometer up to the light and observe the contact point. If there is contact, a very fine gray meniscus will be visible at the contact point. Alternatively, the plunger and adjustment nut are in contact if a thin slip of paper (or a .0001 inch feeler gauge) cannot be slipped between the plunger and the adjustment nut. The adjustment can also be checked by holding the penetrometer vertically in one hand, while pressing on the handle very lightly with one or two fingers of the other hand. The dial should just begin to move.

Adjusting the contact between the dial plunger and the adjustment nut should rarely be necessary. If necessary, turn the adjustment nut counterclockwise to make contact.

Taking Soil Strength Measurements

Press the reset button to release any previous reading, then loosen the dial lock knob and set the dial to zero. Resetting the dial to zero will need to be done frequently to compensate for the effects of temperature changes on the proving ring.

Push the penetrometer into the soil slowly and steadily, keeping the pressure on the handle as even as possible. Over time, and with practice, consistent readings should be readily achieved. For reference, a marker 3 inches from the top of the cone can be made using colored tape, an "O" ring, or a rubber band.

The dial on the penetrometer reads in increments of 0.0001 inches of proving ring deflection. This deflection can be read directly as cone index (ci) when using a 1/2-inch 30-degree cone tip.

There are many models and styles of penetrometers. Each type will have slightly different operating instructions.

Consistency

Consistency is important when making measurements and observations. Persons making the measurements and observations need to be trained by a qualified professional. Training should include operation and maintenance of the penetrometer, operation and maintenance of the tensiometer and moisture meter, visual indicators of soil failure, and principles of soil behavior as it relates to OHV traffic.

Other Applications

When developing predictive curves for an Enduro event, many vehicle passes are needed to simulate the pumping effect of Enduro traffic. When making measurements for Enduro events, measurements should be taken on treads as well as on rolling dips. If in a drying front, tread measurements for an Enduro should be taken at 4 inches. This will vary with the type of vehicles, the amount of traffic, and whether the site is in a wetting or drying front, so some experimentation is needed.

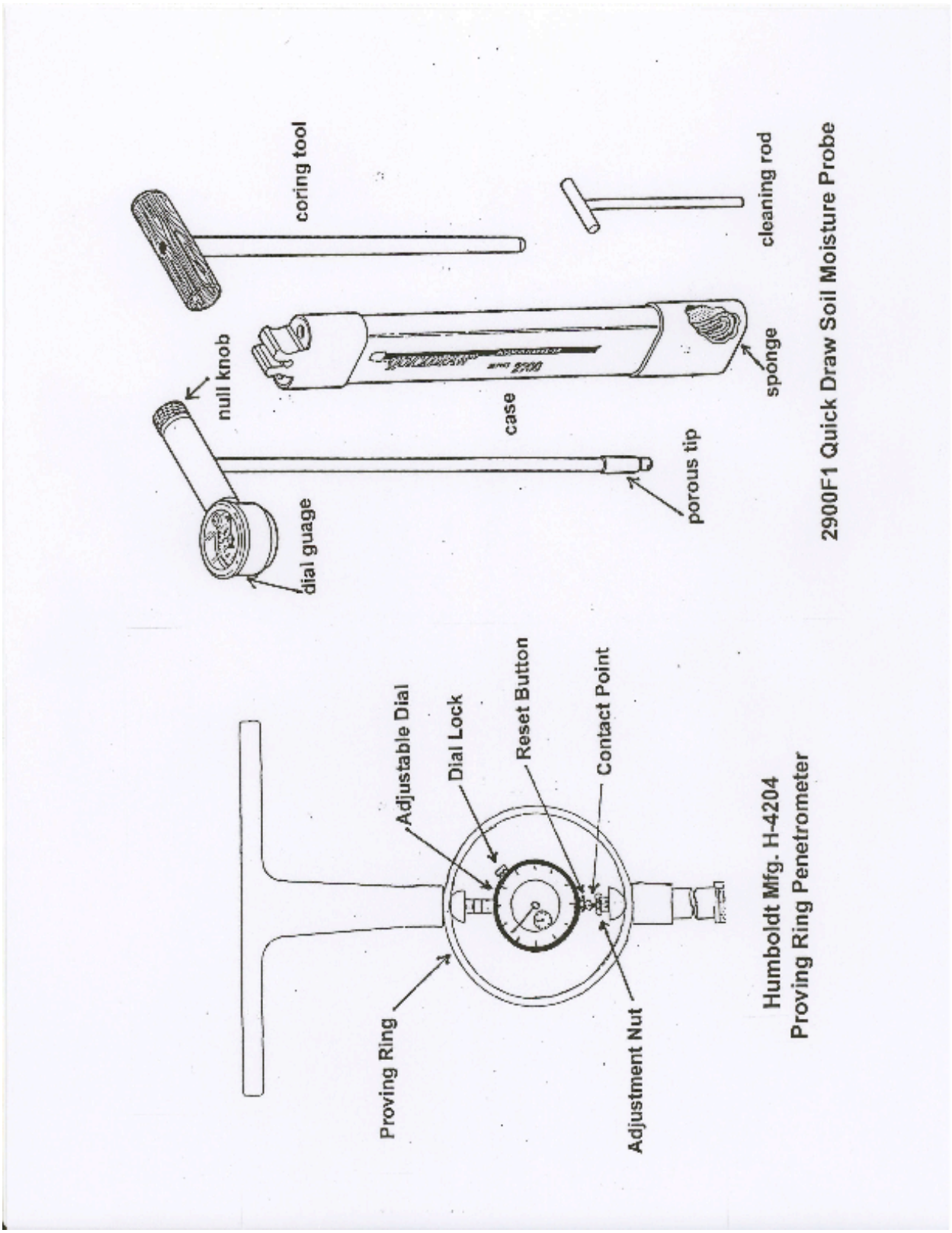
coring tool
cleaning rod
null knob
case
sponge
dial guage
porous tip
2900F1 Quick Draw Soil Moisture Probe
Adjustable Dial
Dial Lock
Reset Button
Contact Point
Proving Ring
Adjustment Nut
Humboldt Mfg. H-4204
Proving Ring Penetrometer

Figure 3.

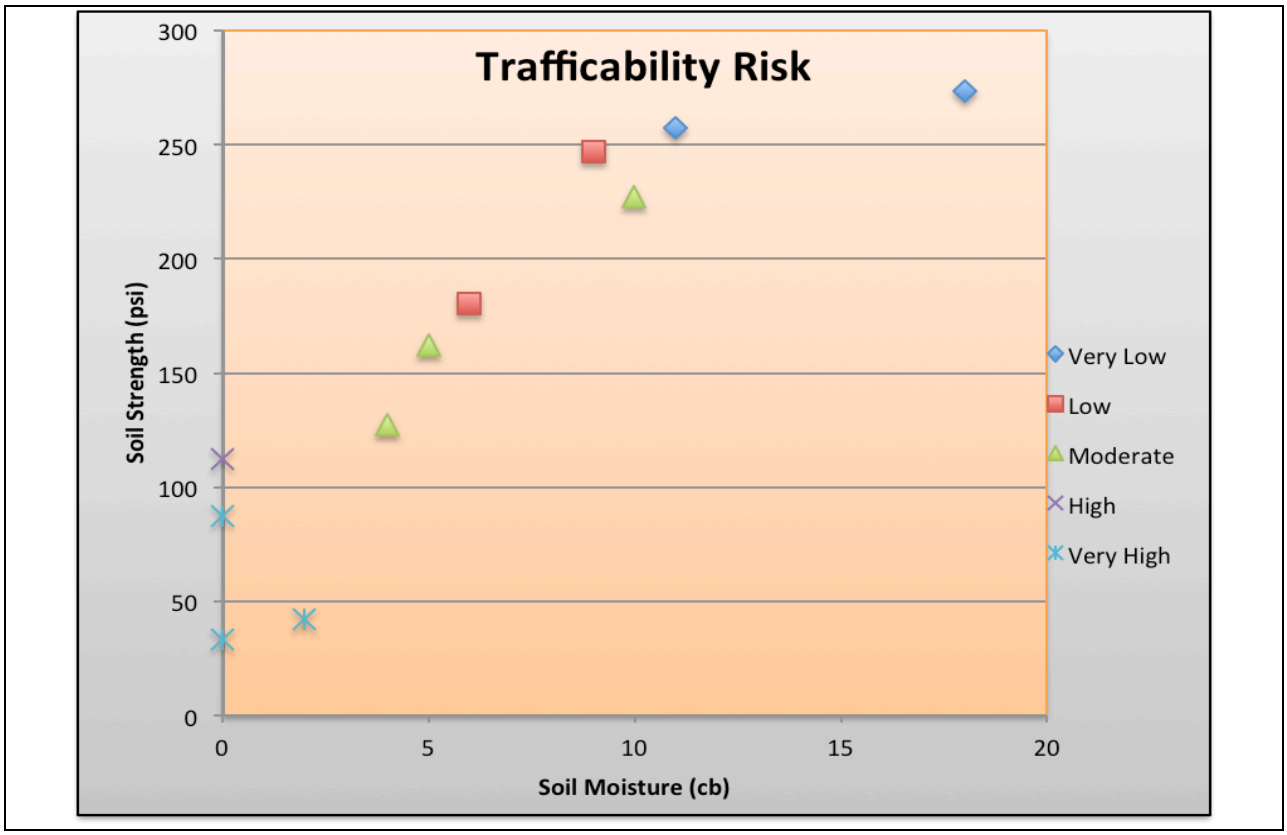

Figure 4.

Delta T HH150 Kit

Insertion of Delta T SM150 Moisture Sensor

Taking Moisture Reading on Delta T HH150 Moisture Meter

Area _____ Trail Name/Number _____ By _____ Date _____

Soil Type (mapped) _____ Soil Type (observed) _____ Last pptn _____ Wetting __ Drying __

Point	Location (GPS)	Dip	Tread	Other	G/M/P	Condition Description	Deflection .0001 in	Moisture cb	Comments

Notes _____

_____

_____

_____

_____Sheet ___ Of __